Neutrinoless Double Beta Decay Status and Prospects

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Abstract

It is very important problem in physics whether neutrino is Dirac or Majorana particles. If neutrinos are Majorana particle, the neutrinoless double beta decay ($0\nu2\beta$) may occur. It is very big impact on particle physics such as effective neutrino mass and mass hierarchy determination. In addition $0\nu2\beta$ mode is lepton number violation process. The current status of $0\nu2\beta$ search experiment was presented.

1 Introduction

By the discovery of the atmospheric neutrino oscillation [1], it was found that the neutrino had finite mass. However, the neutrino mass scale is still not understood. If $0\nu2\beta$ signal is observed, there are very important impacts for particle physics, such as the effective neutrino mass, mass hierarchy determination and evidence of Majorana particle. In addition, the $0\nu2\beta$ is a lepton number violating process. There are many $0\nu2\beta$ search experiments in the world using various detectors and BG reduction techniques. $0\nu2\beta$ signal is very rare events. The current limit of $0\nu2\beta$ half life is more than 10^{26} year [2]. In addition, the tail events of normal two neutrino emitted double beta decay ($2\nu2\beta$) events became BG of $0\nu2\beta$ signal. So $0\nu2\beta$ search experiment is required ultra low BG detector with high energy resolution.

2 Current status

The current status of the $0\nu2\beta$ search experiments is listed Table1. There are many current running or proposed experiments for $0\nu2\beta$ search to reduce BG and achieve high energy resolution at signal region. I categorized 5 types of $0\nu2\beta$ search experiment based on BG reduction technique, such as LS based detector, Xe TPC, Bolometer, Tracking and Germanium detector.

KamLAND-Zen and SNO+ experiment reuse large neutrino detector. Xenon or Tellurium loaded Liquid Scintillator (LS) is feed into the detector. KamLAND-Zen experiment was used 1 kton liquid scintillator detector to achieve ultra low BG environment. The current main BGs of $0\nu2\beta$ search in the KamLAND-Zen experiment [2] are ^{214}Bi, ^{10}C and $2\nu2\beta$ tail events. Usually ^{214}Bi events are tagged using Bi-Po continuum decay. However, in case that the α-particle emitted by the ^{214}Po decay stops in the mini-balloon film which is a dead region for the energy deposition by radiation, the ^{214}Bi events become BG for the $0\nu2\beta$ search. They plan to make new mini-balloon using thin scintillation film. There is no dead region for the energy deposition by radiation. Therefore, the ^{214}Bi events are reduced by the tagging of Bi-Po continuum decay.

Experiment	**Isotope**	**Exposure** (kg yr)	$\mathbf{T_{1/2}}$**limit** (x10^{25}yr) 90% C.L.	**mass limit** (meV)	**Ref**
KamLAND-Zen	^{136}Xe	504	10.7	61 - 165	[2]
EXO-200	^{136}Xe	234.1	3.5	93 - 286	[3]
GERDA	^{76}Ge	53.9	9.0	104 - 228	[4]
Majorana demo.	^{76}Ge	26	2.7	200 - 433	[5]
CUORE	^{130}Te	372.5	3.2	75 - 350	[6]
CUPID-0	^{82}Se	5.29	0.35	311 - 638	[7]

Table 1: Current running or concluded $0\nu2\beta$ search experiment

SNO+ experiment use Tellurium loaded liquid scintillator. The concentration of Tellurium in LS is 0.5% for 1st phase. The LS filling was started in last year. The Tellurium plants commissioning is started. They estimates the main BG is 8B solar neutrino. Target sensitivity is 1.9×10^{26} yr for 5 yr data taking.

EXO-200 experiment used liquid xenon time projection chamber (TPC) detector. Using event multiplicity to recognize the dominant gamma ray BG, the gamma ray BG was rejected. The data taking started in 2011 as a phase I. After electronics upgrade and Rn reduction, the phase 2 started in 2016. In Dec.2018 the EXO-200 data taking was finished. The main BGs are ^{214}Bi and ^{208}Tl. Total exposure is 234 kg yr. $0\nu2\beta$ half life limit is more than 3.5×10^{25} yr. EXO collaboration plan to upgrade liquid xenon TPC detector toward ton scale detector. The nEXO detector will be constructed in SNOLAB. The mass of enriched Xenon is 5 ton and the sensitivity reached to 9.2×10^{27} yr [8].

NEXT experiment is high pressure xenon gas TPC detector. Current NEXT-white phase is running to demonstrate the energy resolution at Q value and the topological BG reduction. $0\nu2\beta$ signal has two blobs at endpoints. On the other hand BGs like gamma ray and single beta is only one blob. They achieved 1% (FWHM) energy resolution at 2.6MeV [9]. Ton scale detector sensitivity reach more than 1×10^{27} yr for 3 years data taking.

CUORE experiment use 988 Tellurium oxide crystals. The CUORE detector is bolometer detector. The operation temperature is 10mK. The thermal signal is detected. There were many BGs near signal region. The dominant BG is alpha particles from the surface of crystal.

CUPID experiment is upgrade program of CUORE with particle identification. In addition the thermal signal, they detect light signal. Using pulse shape of the light signal, the alpha BG could be reduced drastically. Zinc Selenium crystal was used to demonstrate Scintillating bolometer technique.

GERDA and Majorana experiments used high purity Germanium detector GERDA experiment achieved BG free $0\nu2\beta$ search. The energy resolution of Germanium detector is 3 keV at Q value. Majorana demo used 44.1kg Germanium detector. The Germanium detector is point contact detector. Many gamma ray BGs was reduced using pulse shape information. LEGEND is upgrade program of GERDA and MAJORANA experiment. LEGEND plant to construct ton scale Germanium detector array. The 3 sigma discovery potential reach 1×10^{28} yr.

3 Conclusions

The current status of the effective neutrino mass limit is near the Inverted Hierarchy region. There are many proposed experiments to fully covered the Inverted Hierarchy region. If the effective neutrino mass sensitivity reach 15 meV, the half of Normal Hierarchy region is covered.

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